Neutrino telescope and CMB likelihoods: implications for the MSSM

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Based on:
PS, Savage, Edsjö & The IceCube Collab. *JCAP* 2013, arXiv:1207.0810
Silverwood, PS, Danninger, et al. *JCAP* 2013, arxiv:1210.0844
Cline & PS *JCAP* 2013, arXiv:1301.5908

Slides available from:
`http://www.physics.mcgill.ca/~patscott`

Likelihoods: why should theorists care?

1. Gives full info on how consistent a given model is with data (not IN/OUT) $\longrightarrow$ allows global fits
2. Allows proper recasting of experimental results to different models
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Likelihoods for beyond-the-SM searches to be described:

- CMB angular power spectrum distortions:
  Energy injection from DM annihilation $\chi\chi \rightarrow SM$ at $z \sim 600$
- Neutrino signals from the centre of the Sun:
  Solar WIMP capture and annihilation

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Models:

- CMSSM: m_0, $m_{\frac{1}{2}}$, A_0, $\tan\beta$, μ
- MSSM-25: M_1, M_2, M_3, $15 \times m_{\tilde{f}}$, A_t, A_b, A_τ, $A_{e/\mu}$, m_A, $\tan\beta$, μ

Generalised DM CMB likelihood functions

Simple CMB likelihood function, for

- Any combination of annihilation or decay channels
- Any dark matter mass
- Any decay lifetime/annihilation cross-section

$\longrightarrow$ just requires interpolating one number in a table.

Cline & PS, 1301.5908, using

- CMB energy deposition from Slatyer, 1211.0283 and Finkbeiner et al, 1109.6322
- PYTHIA annihilation/decay spectra of Cirelli et al, 1012.4515.

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η for decay:

$$\ln \mathcal{L}(\tau | m_\chi, r_i) = -\frac{1}{2}\left(\frac{\delta\Omega}{\Omega_{\rm DM}\tau}\right)^2 \eta^2(\tau, m_\chi, r_i) \quad (2)$$

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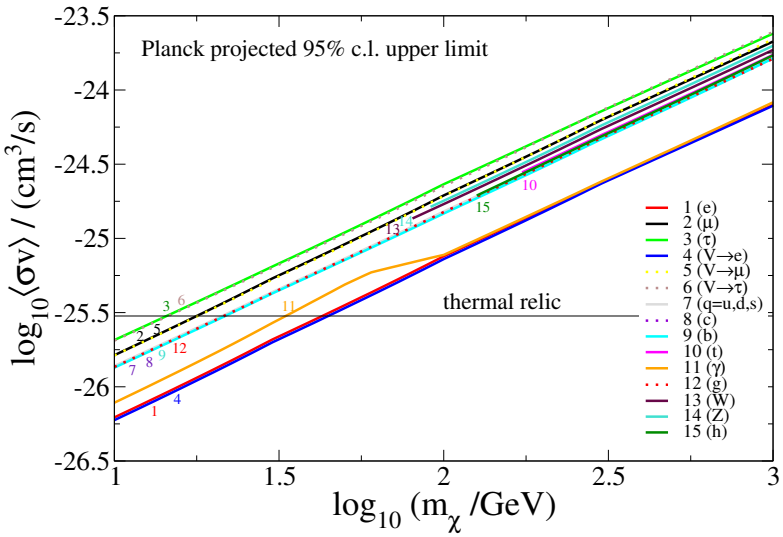

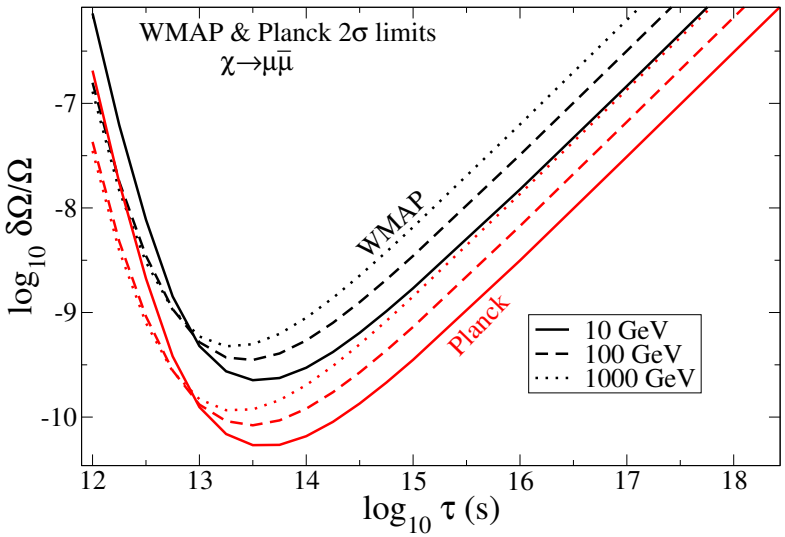

How to find DM with neutrino telescopes

The short version:

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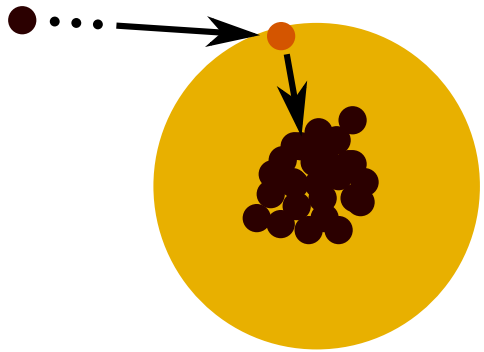

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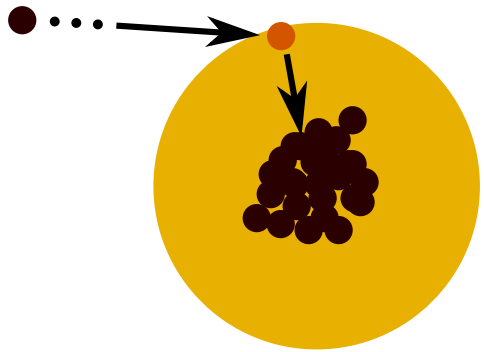

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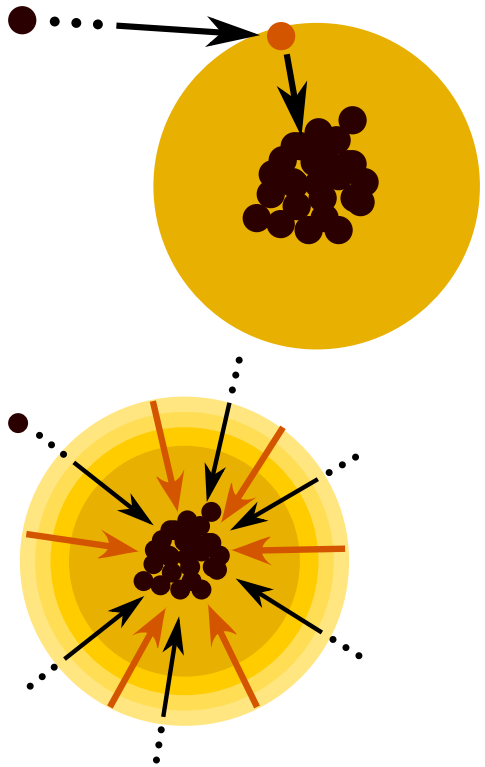

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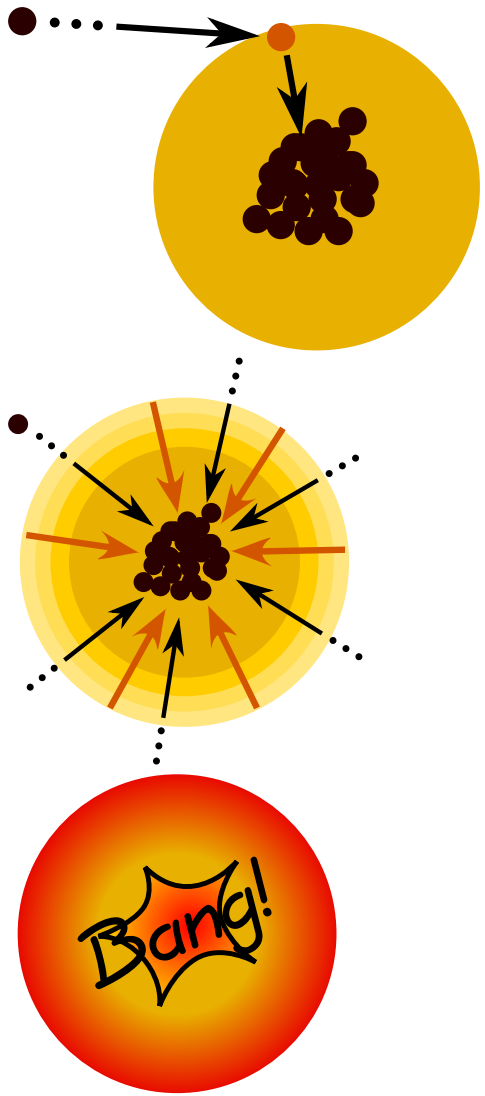

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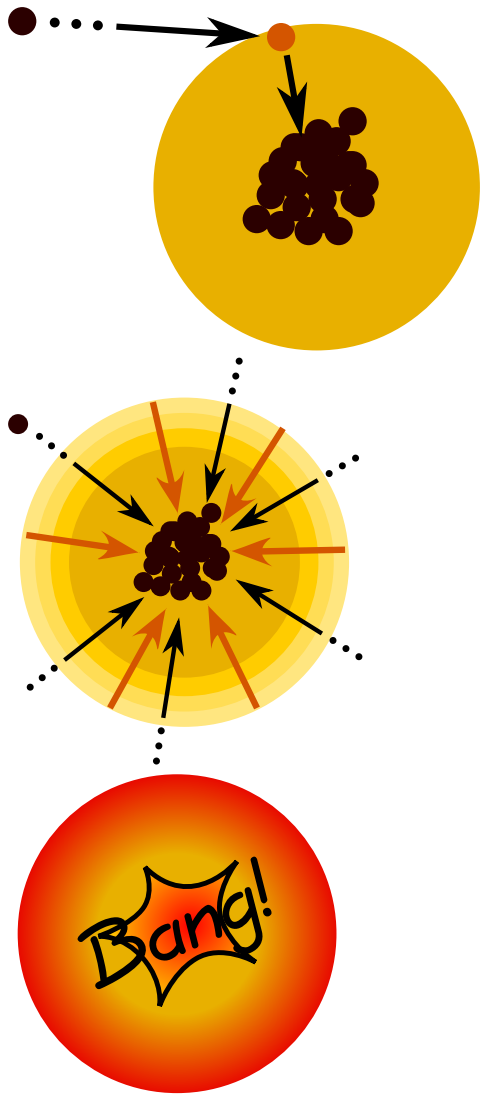

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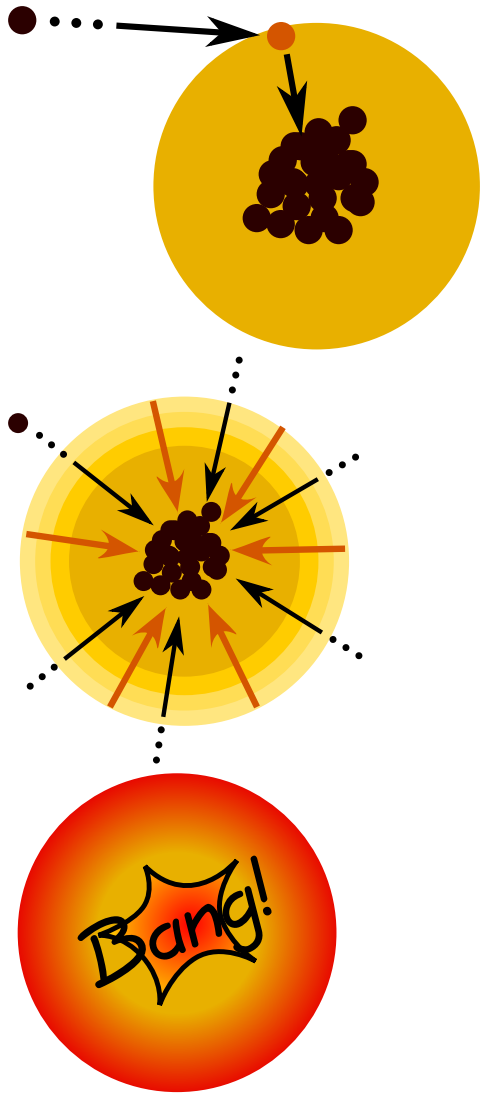
6. Look for Čerenkov radiation from the muons in **IceCube**, ANTARES, etc



Advanced IceCube Likelihood for Model Testing

Simplest way to do anything is to first make it a counting problem...

Compare observed number of events n and predicted number θ for each model, taking into account error σ_ϵ on acceptance:

$$\mathcal{L}_{\rm num}(n|\theta_{\rm BG}+\theta_{\rm sig}) = \frac{1}{\sqrt{2\pi}\sigma_\epsilon}\int_0^\infty \frac{(\theta_{\rm BG}+\epsilon\theta_{\rm sig})^n e^{-(\theta_{\rm BG}+\epsilon\theta_{\rm sig})}}{n!}\frac{1}{\epsilon}\exp\left[-\frac{1}{2}\left(\frac{\ln\epsilon}{\sigma_\epsilon}\right)^2\right]{\rm d}\epsilon\,. \tag{3}$$

Nuisance parameter ϵ takes into account systematic errors on effective area, etc. $\sigma_\epsilon \sim 20\%$ for IceCube.

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Then: upgrade to full unbinned likelihood with number ($\mathcal{L}_{\rm num}$), spectral ($\mathcal{L}_{\rm spec}$) and angular ($\mathcal{L}_{\rm ang}$) bits:

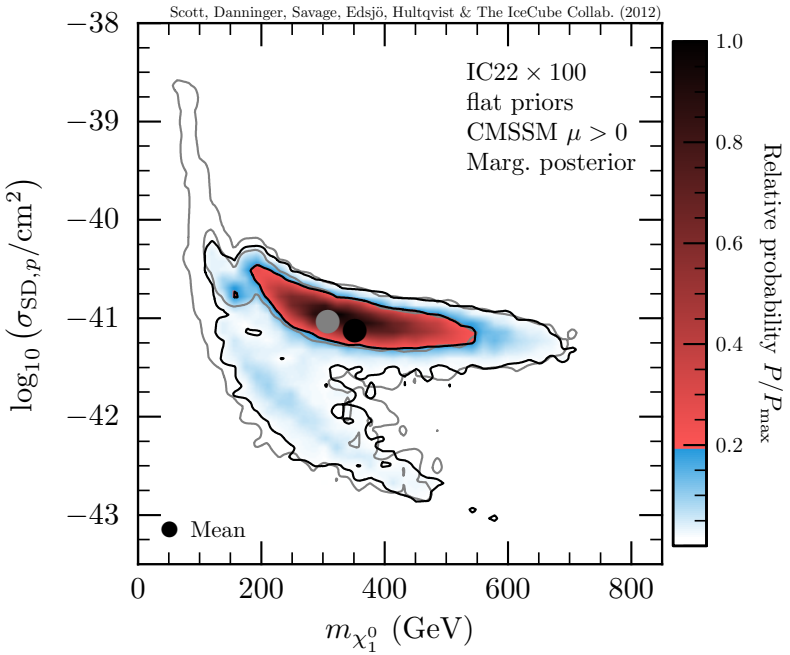
$$\mathcal{L} = \mathcal{L}_{\rm num}(n|\theta_{\rm signal+BG})\prod_{i=1}^{n}\mathcal{L}_{{\rm spec},i}\,\mathcal{L}_{{\rm ang},i} \tag{4}$$

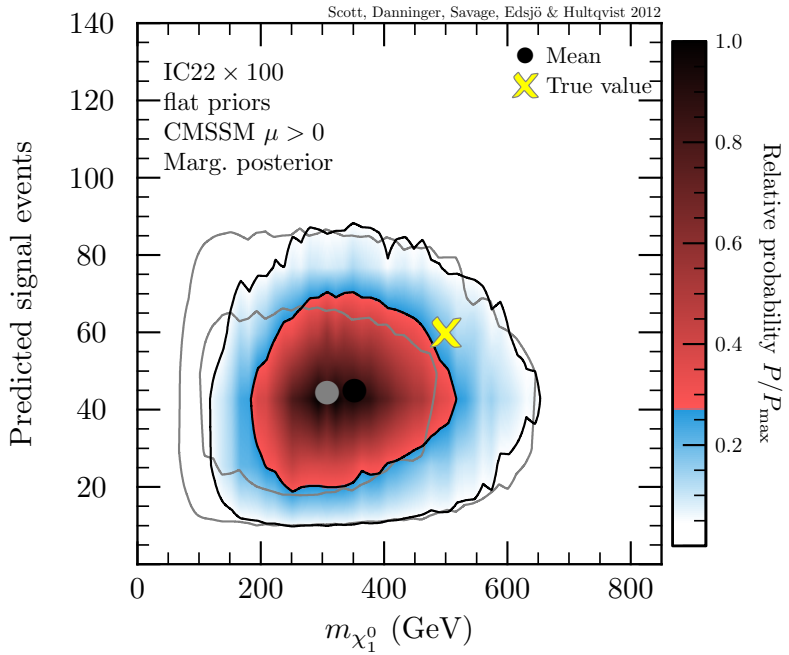
All available in DarkSUSY v5.0.6 and later: www.darksusy.org

CMSSM model reconstruction with IceCube event data

Benchmark recovery with 22-string IceCube WIMP-search neutrino events + full likelihood:

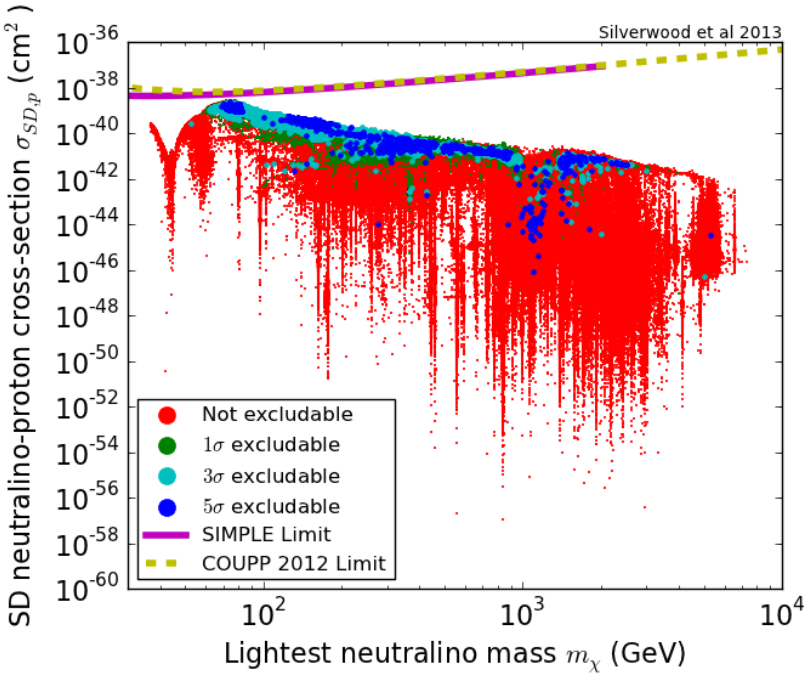
Mock signal: 60 events, $m_\chi = 500\,\mathrm{GeV}$, 100% $\chi\chi \to W^+W^-$

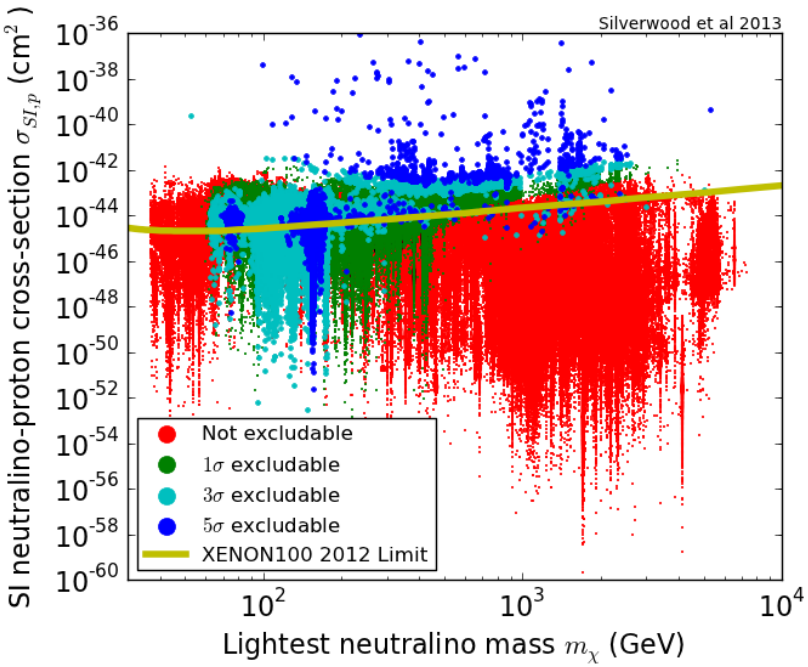




Prospects for detection in the MSSM-25

86-string IceCube vs Direct Detection (points pass $\Omega_\chi h^2$, $b \to s\gamma$, LEP)

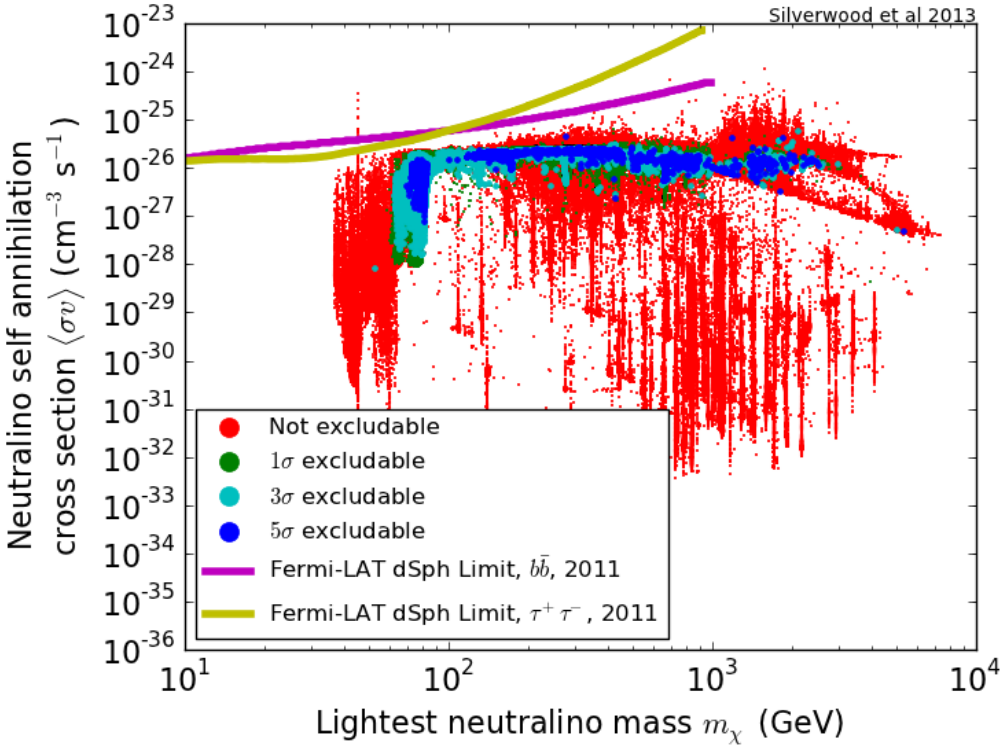




Many models that IceCube-86 can see are not accessible to direct detection…

Prospects for detection in the MSSM-25

86-string IceCube vs Gamma Rays

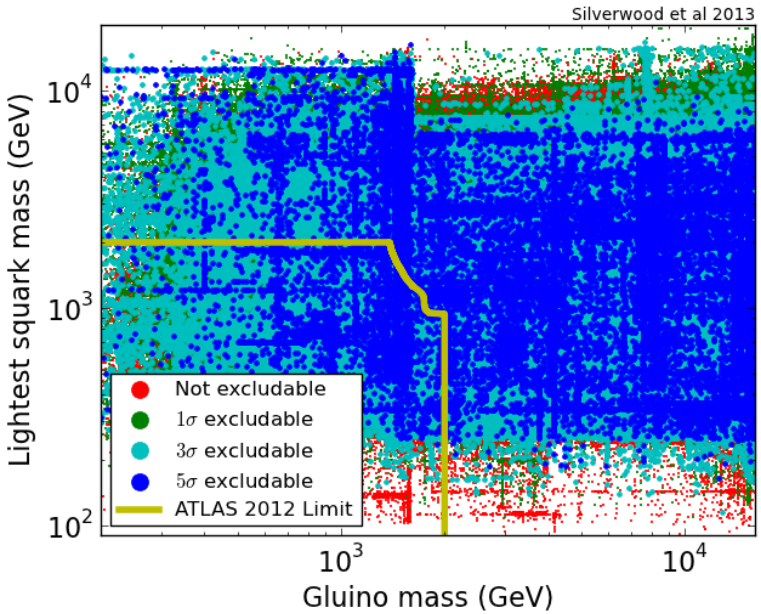


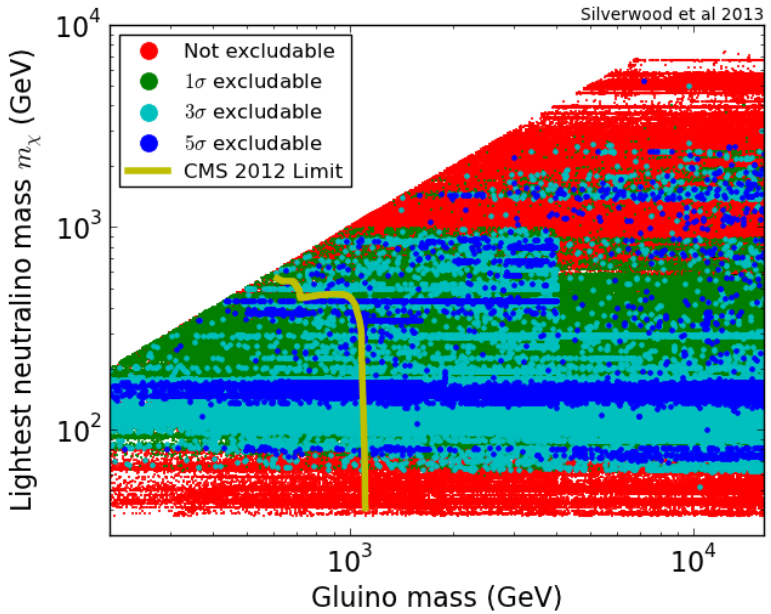
Many models that IceCube-86 can see are not accessible by other indirect probes…

Prospects for detection in the MSSM-25

86-string IceCube vs LHC (very naively)

SMS limits: 7 TeV, 4.7 fb^{-1}, jets + $E_{T,miss}$; 0 leptons (ATLAS), razor + M_{T2} (CMS)





Many models that IceCube-86 can see are also not accessible at colliders.

Summary

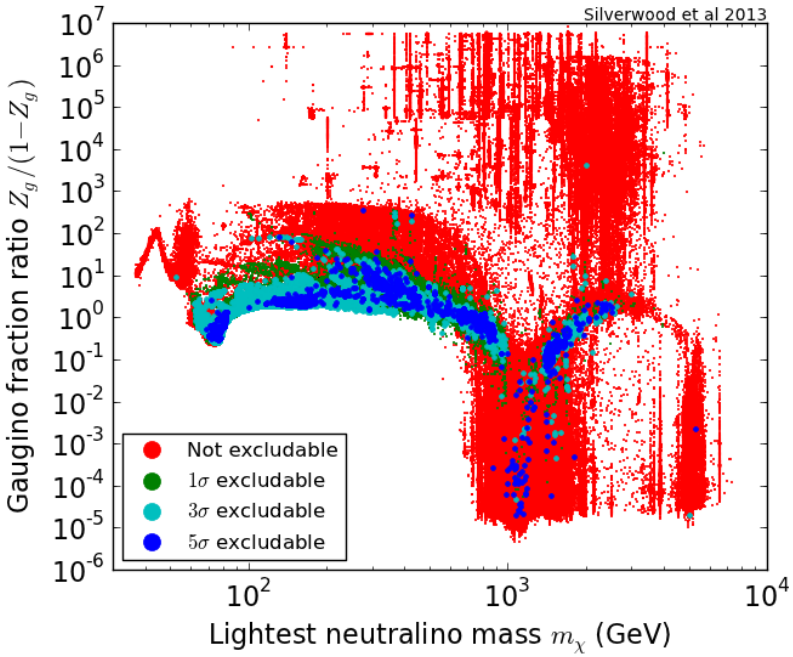
Take-home messages:

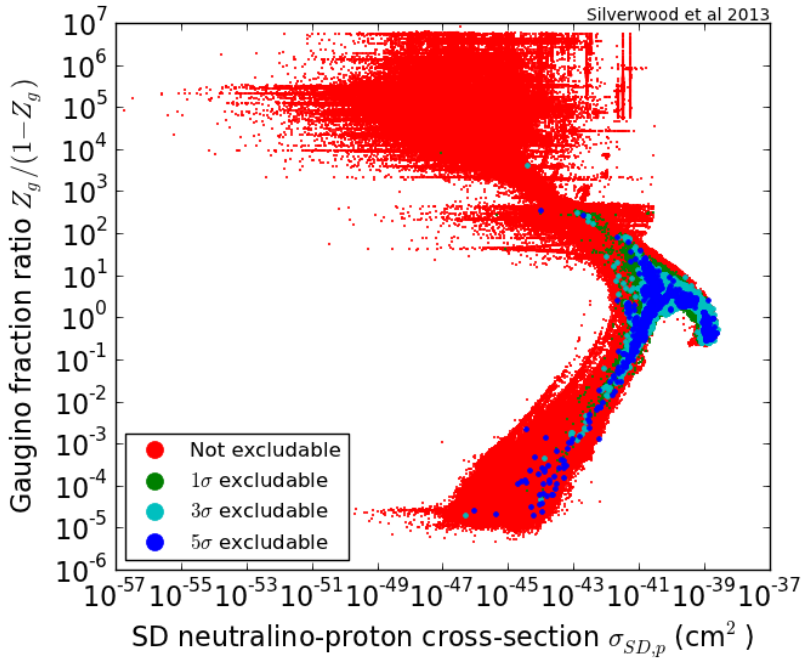
1. Limits are not enough – experiments need to give full likelihood information if phenomenology is to be done properly
2. Neutrino telescopes provide the only access to many MSSM-25 models
3. Energy information in neutrino DM searches can help greatly in model discrimination

Backup Slides

Prospects for detection in the MSSM-25

Gaugino fractions





Mainly mixed models, a few Higgsinos